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COMPUTATIONAL STUDY ON PERFORMANCE OF RAMJET ENGINE FOR VARIOUS MACH NUMBERS

M. SADHIQ[1], MAMIDI AJAY SAGAR[2], N. RAJASEKHAR RAYUDU[3] & D. SMITHA[4]

[1,3]Student, Department of Aerospace Engineering, Jawaharlal Nehru Technological University Hyderabad, India

[2]Assistant Professor, School of Aeronautics Neemrana, Rajasthan, India

[4]Associate Professor, Malla Reddy Institute of Engineering & Technology, India

ABSTRACT

This research focuses on the modelling and simulation of combustion dynamics in lean premixed 2-D axisymmetric Ramjet engine for Mach number 3, 3.5, 4 and 4.5. Current research is to establish proper premixing of flow with fuel and generate proper conditions for combustions. Intake design is the primary objective for generating proper shock waves to reduce, and it enters the ramjet during supersonic speeds. Study includes proper combustion by reducing supersonic flow to subsonic before the combustor, and also proper mixture of air and fuel. Different air fuel ratios are considered and concluded by most efficient Air fuel mixture ratio. Meanwhile, aerodynamic properties such as pressure and temperature lead us to study the flow mixture.

KEYWORDS: Supersonic Air Intake, Subsonic Combustion, Combustion Chamber, C-D nozzle, Internal and External Flow & CFD-Fluent

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Original Article

1. INTRODUCTION

Huge advancements in Air-breathing propulsion technology took place in the past three decades. [1]Thedemandfor augmenting productivity and speed of the vehicle and care for the environment play a major key role during designing. So, scientists break through with a solution for Ramjet engine. [2]An air-breathing engine generates thrust without any rotating parts and travels faster than sound. In the background, it originates thrust by evolving supersonic air from the available atmosphere and recedes to subsonic air by causing ram-e□ect during intake. So that, combustion takes place in subsonic speed and produces required thrust through nozzle exit. A series of oblique shocks form ahead of intake results to rise in pressure. Essentially, ramjet acquires highest Thrust Specific Fuel Consumption's (TFSC) about Mach 2-5, comparing turbofan and turbojet engines. It has a unique ability to provide continuous thrust, sustaining high supersonic speeds and high specific impulse.

[3]G. Raja Singh Thangadurai concluded the overall performance of an integrated ramjet engine, comprising of air intake combustor and nozzle, had through full engine simulation. [4]Hebrard employed a combined approach using experiments in isothermal conditions and simple computation models, to study the overall performance of various ramjets. The choice and techniques of ramjet designs are discussed by Cazin and [5]Laurent. A numerical analysis is conducted on entire ramjet to understand the combustion characteristics by [6]Sung. Gaiddon and Knight used an automated phase of CFD tools for improving the performance of ramjet.

2. BOUNDARY CONDITIONS

Boundaries are to be chose judiciously. They were used to get perfect realistic solutions. Specified conditions are applied in this problem.

- On solid surface: no-slip adiabatic boundary is applied specifying pressure as input.
- A medium of free stream is employed in between Inlet and outlet by holding particular altitude.
- Axis-symmetric boundary condition is employed along the axis.

3. NUMERICAL STUDY

The turbulence model used in the present computational study is the standard $K - \varepsilon$ model, which implies two PDE to calculate velocity and distance scale of turbulence. A standard enclosure function described by launders and Spalding is used in our calculations.

$$k_t = \alpha\left(\frac{k^2}{\varepsilon}k_x\right)_x - \varepsilon$$

$$\varepsilon_t = \beta\left(\frac{k^2}{\varepsilon}k_x\right)_\varepsilon - \gamma^2\frac{\varepsilon^2}{k}$$

Where, k = k(x, t) it the turbulent kinetic energy $\varepsilon = \varepsilon$(x, t) is the rate of dissipation of turbulent energy and α, β and γ are positive constrains.

Even though, the true development of the model is often credited to jones and Launder, it should be noted that (KE) sometimes referred to as the $b - \varepsilon$ model, in acknowledgement of Kolmogorov's. Original insight and relationship between the variables used: $b = \frac{2}{3}k$b whereω and $b$are proportional to ε.

Mass flow rate of the air and fuel mixture is given as $\rho_e U_e A_e = \dot{m}_a + \dot{m}_f$

Therefore, the Thrust obtained by the ramjet is given by $T = \dot{m}_a(U_e - U_0) + (P_e - P_0)A_e + \dot{m}_f U_e$

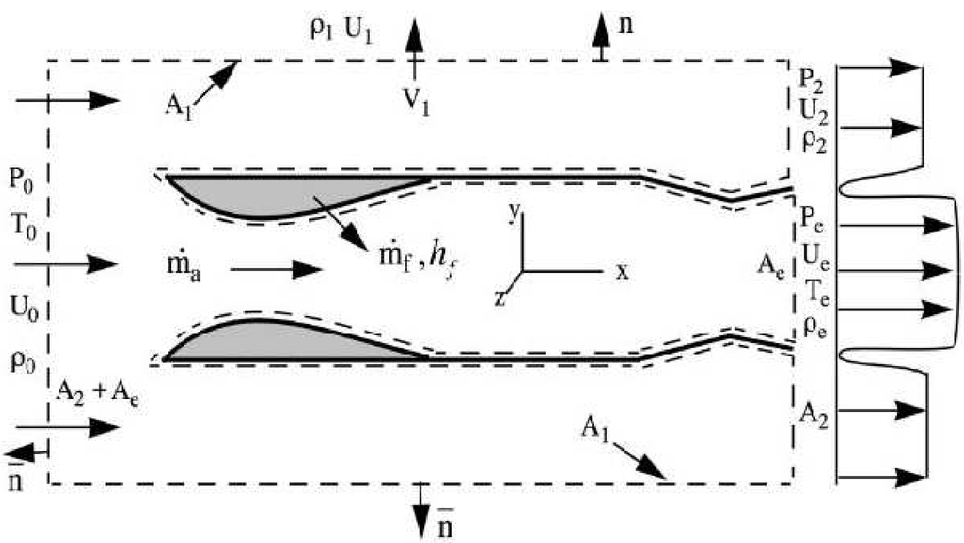

Figure 1: Ramjet Control Volume for Developing a Definition of Thrust.

4. MODELLING AND SIMULATION

Complete study helps us to locate and resize the air intake as well as combustor geometry of Ramjet. However, a crucial factor which needs deep consideration is the nozzle flow. On other hand, during supercritical condition, shock train moves in the diffuser to recover pressure that may again lead to poor results in lower efficiency. The study of cold flows gives the performance of the engine in all the sections, before and after fuel mixture.

This arrangement is useful in analysing the ramjet engine in totality. Entire model is designed using ICEM CFD and a fine mesh is generated consisting of 62000 elements in it. Quadrilateral elements are generated with equal size of elements. Later, the model is imported to FLUENT for further simulation study by generating turbulent flow. Boundary conditions are allotted, the body is stationary and the flow is simulated by generating pressure far-field around the ramjet.

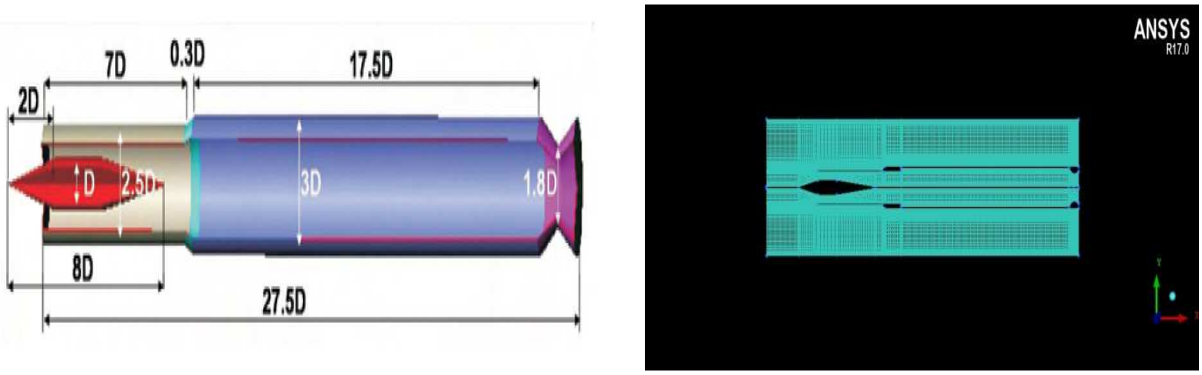

Figure 2: Geometry Considered Mesh.

5. RESULTS AND PLOTS

The anticipated static pressure and Mach contours for free jet flow analyses of an exemplary case are showed in following figures, respectively. By enlarging combustion chamber, the normal shock manoeuvre further downstream inside the air duct. The oblique shock, attached to the tip of the cowl body and also near the sudden enlarge suction in the external flow is clearly shown in the contours. Pressure preferred from M=3, 4 and 4.5 are plotted. A difference of 3-bar pressure is observed, as the rise in Mach number the pressure also increases. These results are compared by G. Raja singh Thandurai, B. S. Subhash Chandran, V. Babu, & T. Sundararajan. In the paper, Numerical Analysis of Integrated Liquid Ramjet Engine.

At a higher Mach number, the static pressure recovery is also greater as expected. A closer scrutiny of the Mach number contours reveals reflected oblique shock patterns in the intake region. Expansion of the flow (compressed by shock in the intake) is observed across the nozzle. Stream function contours are shown in Fig. 5. A re-circulation zone is observed, where there is sudden enlargement in the combustion chamber area. The size of the re-circulation eddy is seen to increase with Mach number.

Thus, the cold study ow is performed successfully and desired pressure is obtained with proper fuel mixing. All the fuel losses are predicted and proper care was taken to mix the fuel with air such that, no fuel misses during the mixing. Fuel injection is studied for proper mixing of the flow.

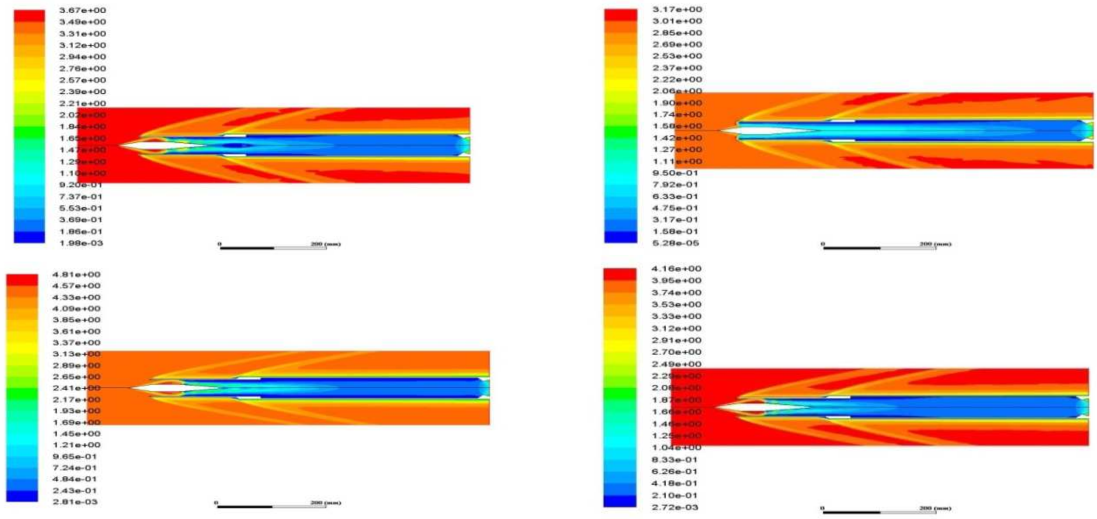

Figure 3: Mach Contours.

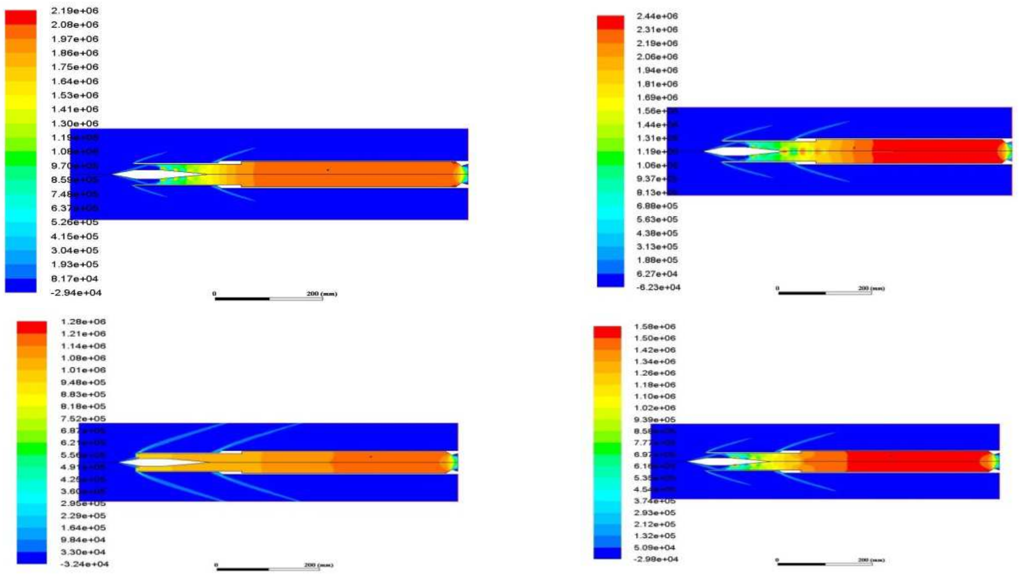

Figure 4: Pressure Contours.

6. COMBUSTION SIMULATION

Simulation studies were also carried out for a full liquid ramjet engine, comprising all the constituent assemblies such as air-intake, fuel injector, combustion chamber and nozzle. The exact operation has been simulated by injecting fuel in the combustor, immediately. The effect of free stream Mach number and air/fuel ratio (A/F) on the ramjet engine performance have been studied in detail. Full engine simulations have been carried out with two Air to fuel ratios i.e., 17 and 25. The contours of Mach number and static temperature for inlet Mach numbers of3.0, 3.5 and 4.0 are shown, respectively. Firstly, we are performing simulations for air/fuel17.

Mach number contours for inlet Mach number equal to 3 indicate that, the shock train is located outside the intake, which results in spillage of air ow. For Mi = 3.0, the spillage is reduced and the terminal normal shock is located at the entry section. For Mi = 3.5, the shock train moves into the intake, here the feature of reflected oblique shocks culminating in a terminal shock is clearly seen. These three cases of Mi = 3, 3.5 and 4correspond to the sub-critical, critical

(approximately) and super-critical operation of the engine, respectively. From the temperature contours, it is seen that combustion primarily occurs close to the wall, near the sudden expansion section.

The re-circulatory region and boundary layer close to the wall, aid in flame stabilisation. In this study, the conserved-scalar approach based on the fast-chemistry assumption is adopted to account for the turbulence-combustion interaction. The maximum temperature attained is highest for Mi = 3.5, since the shock compression process results in a higher pre-ignition temperature for this case, because of stronger shocks.

7. STUDY OF MASS FRACTION

For Nozzle area ratio 17, even though maximum temperature is higher, the average temperature is lower for Mi =3.0 due to larger mass flow rate. The fuel mass fraction contours are plotted. The static pressure, static temperature and Mach number variation along the surface of the centre body and axis are shown, respectively. The static pressure and temperature increase across the terminal normal shock, while the Mach number decreases to subsonic values. In fact, for M = 3.0, features such as flow deceleration at the first shock re-acceleration, immediately after the shock and subsequent transition to subsonic flow, at the terminal normal shock can be clearly discerned. Also, at M = 3.0, combustion phenomenon does not penetrate up to the axis, and hence temperature rise is marginal along the axis.

For Nozzle area ratio 25, the mass fraction of the fuel is lesser comparing to the previous. It is so because, the mass-flow rate of air is higher than the mass flow rate of the fuel so the mixture couldn't happen properly for higher mach numbers. When coming to M=3.0, the mass fraction is exactly required, so it resulted without any losses. But, when coming to M=3.5 and M=4, due to increase in Mach umber, air flow is higher than the expected, so the fuel and air couldn't mix properly, which resulted in loss of fuel burning that yield in un-burnt fuel.

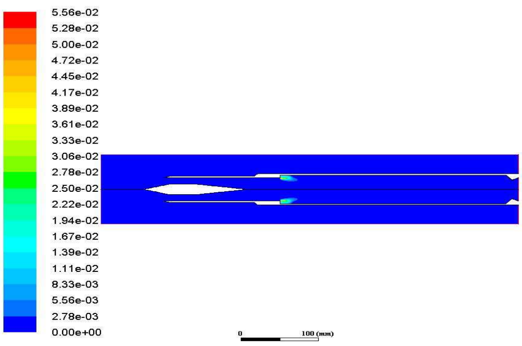

Figure 5: Air/Fuel Ratio 17 M = 3.

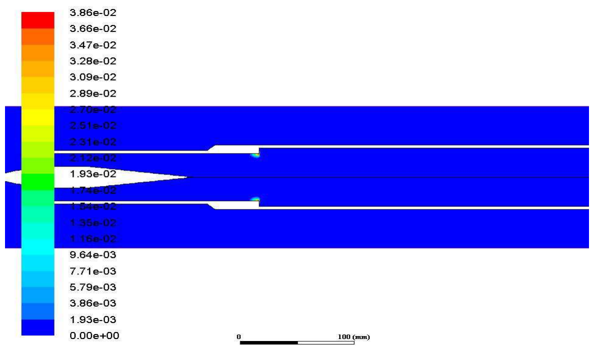

Figure 6: For Air/Fuel Ratio = 25 at M = 3.

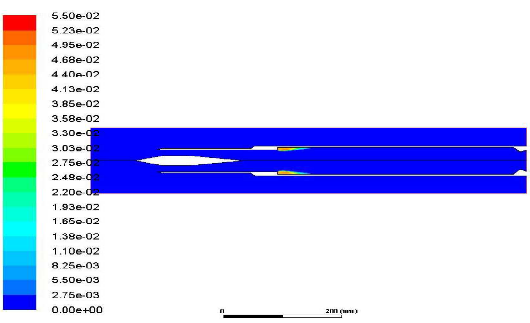

Figure 7: Air/Fuel Ratio 17 at M = 3.5.

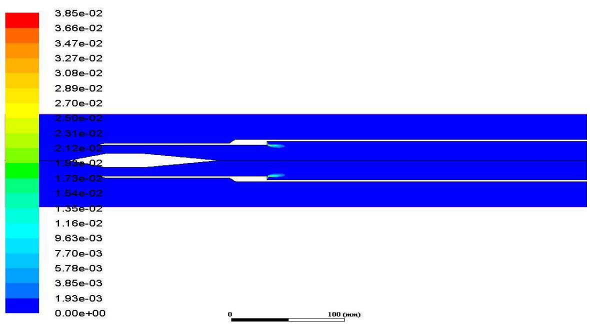

Figure 8: Air/Fuel Ratio 25 at M = 3.5.

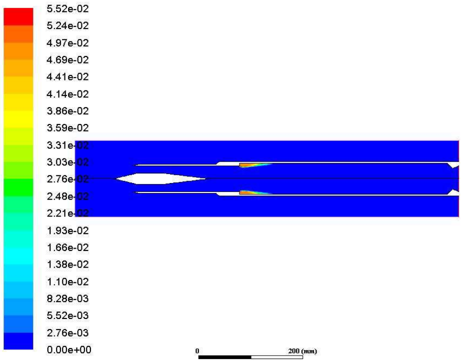

Figure 9: Air/Fuel Ratio 17 at M = 4.

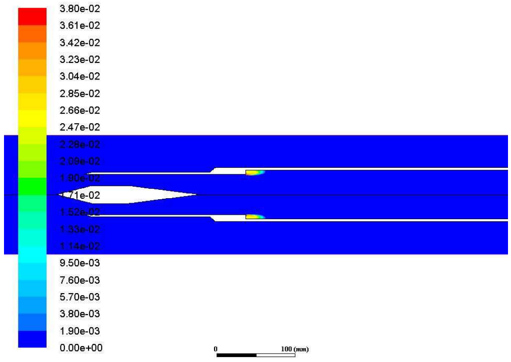

Figure 10: Air/Fuel Ratio 25 at M = 4.

8. PRESSURE STUDY DUE TO COMBUSTION

For Nozzle area ratio 17, pressure generated for M = 3 is lesser than M = 3.5, even though there is no un-burnt fuel loss. So due to this, pressure developed is less. Due to less pressure, the performance of the engine is also bottommost. When coming to M = 3.5, there is higher mass flow rate and fuel rate is also higher, this resulted in developing of higher pressure. Due to high pressure, combustion took perfectly and efficiency of the engine is good. But, when we come to M = 4, the mass ow rate of the air is too high than fuel ratio, due to this, fuel and air mixture couldn't take place properly and resulted in pressure loss.

Coming to the Nozzle area i.e. ratio 25 air-fuel ratio, the Mach number increases as the pressure decreases. It is so because For M = 3, the mass flow rate of air and fuel are equally matched and mixture took place properly, due to this, required pressure is generated. While coming to M = 3.5 and 4, the mass flow rate of air is higher than mass flow rate of fuel. Because of this, pressure losses are higher.

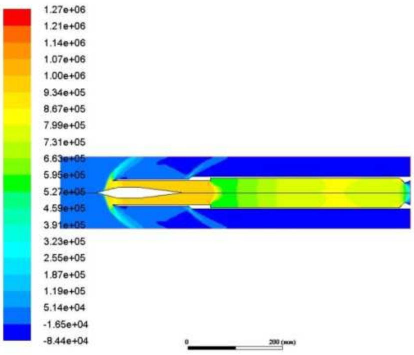

Figure 11: Pressure for Air/Fuel Ratio 17 at M = 3.

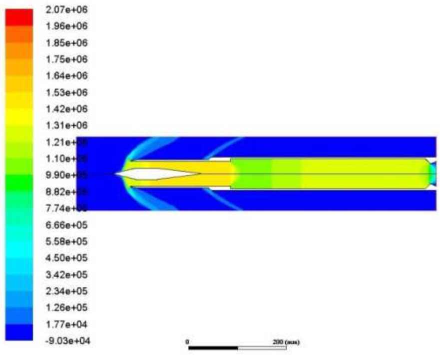

Figure 12: Pressure for Air/Fuel Ratio 25 at M = 3.

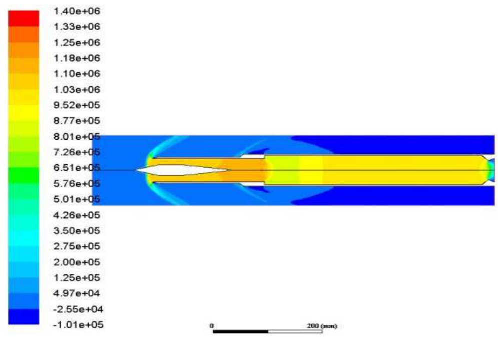

Figure 13: Pressure for Air/Fuel Ratio 17 at M = 3.5.

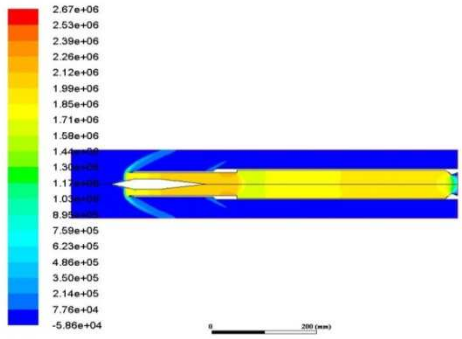

Figure 14: Pressure for Air/Fuel Ratio 25 at M = 3.5.

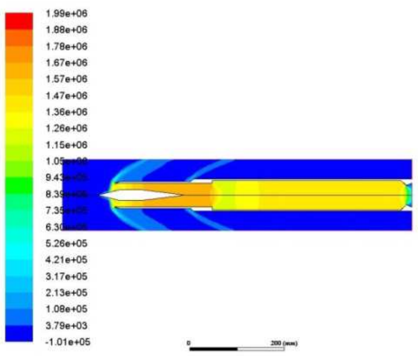

Figure 15: Pressure for Air/Fuel Ratio 17 at M = 4.

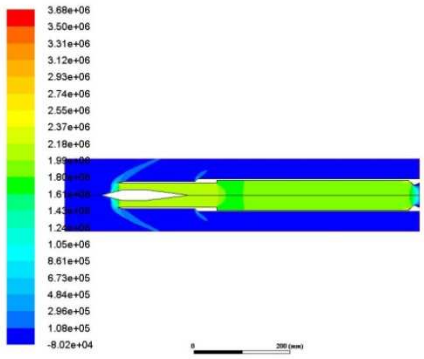

Figure 16: Pressure for Air/Fuel Ratio 25 at M = 4.

9. TEMPERATURE STUDY FOR COMBUSTION

The following contours represent the temperature developed due to the pressure generated for various Mach numbers. Here, we observed that high temperature is recorded for M = 3.5comparing to the rest of the mach numbers M = 3 and M = 4. It is so because; due to pressure losses taken place because of improper air fuel mixture, the temperature losses also took place. This, finally resulted that M = 3.5 gave efficient result in performance of the engine. The following contours represent the temperature developed due to the pressure generated for various Mach numbers. Here, we observed that high temperature is recorded for M = 3comparing to the rest of the mach numbers M = 3 and M = 4. It is so because; due to pressure losses taken place because of improper air fuel mixture, the temperature losses also took place. This, finally resulted that M = 3.5 gave efficient result in performance of the engine.

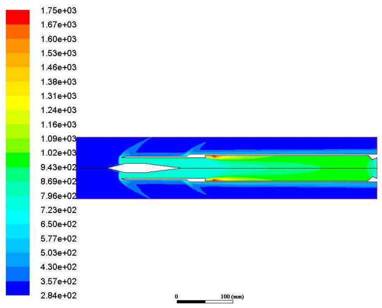

Figure 17: Temperature for Air/Fuel Ratio = 17 at M = 3.

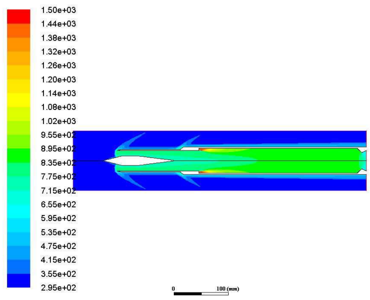

Figure 18: Temperature for Air/Fuel Ratio = 25 at M = 3.

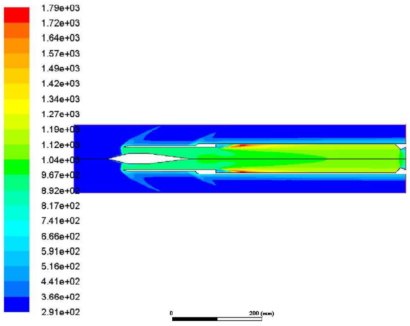

Figure 19: Temperature for Air/Fuel Ratio = 17 at M = 3.5.

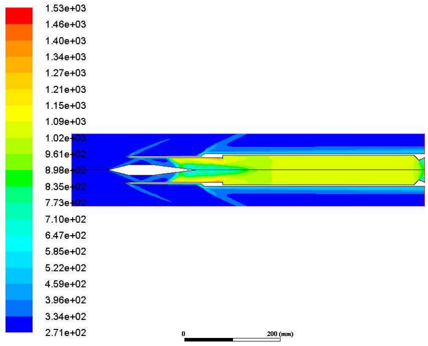

Figure 20: Temperature for Air/Fuel Ratio = 25 at M = 3.5.

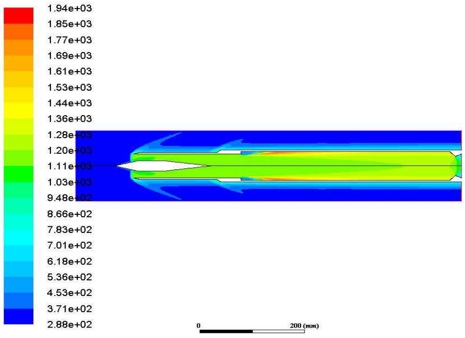

Figure 21: Temperature for Air/Fuel Ratio = 17 at M = 4.

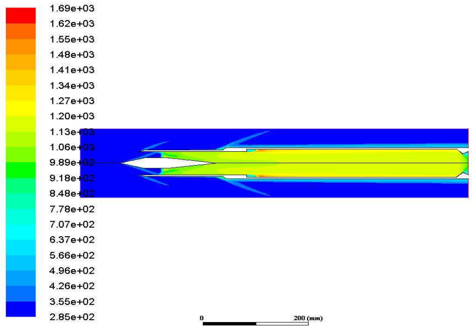

Figure 22: Temperature for Air/Fuel Ratio=25 at M = 4.

10. CONCLUSIONS

In our current research, we discuss about effect of inlet by fluctuating Mach number characteristics of ramjet engine. We compare results obtained for Mach number 3, 3.5 and 4, which gave very interesting results. For every 0.5 Mach increase, the pressure approximately varies up to 2 bars as shown in graph. In the same context, for Air-Fuel ratio=17, we have seen the temperature have increased approximately 200k for every 0.5 Mach increase. It is also recorded that entire combustion took place in subsonic conditions only.

For Air-Fuel Ratio = 25, it was recorded that the change in mass ow rate is effecting the combustion process. Here, due to increase in Air-Fuel Ratio from 17 to 25, the mass ow rate of the air is increased. Due to this, the combustion process has adriftchange and rests at a constant Mach number in subsonic speeds.

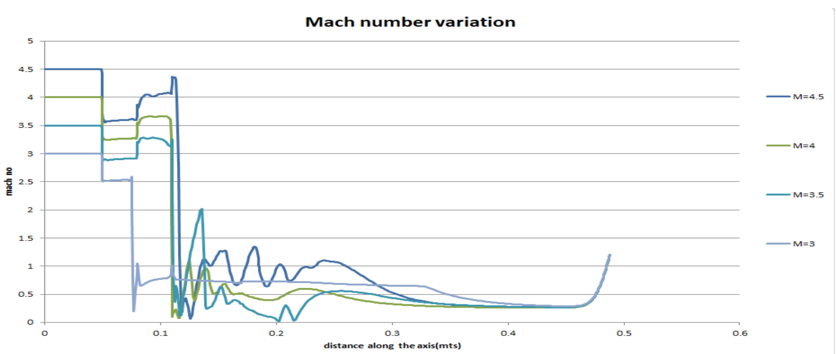

Figure 23: Mach Number Graph.

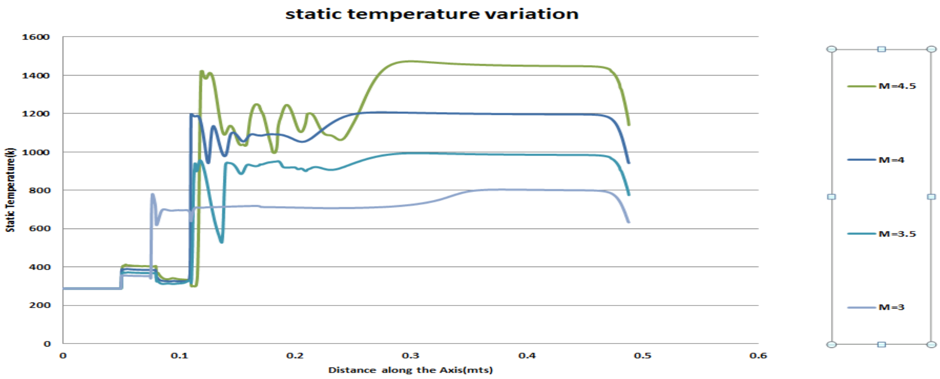

Figure 24: Temperature Variation Graph.

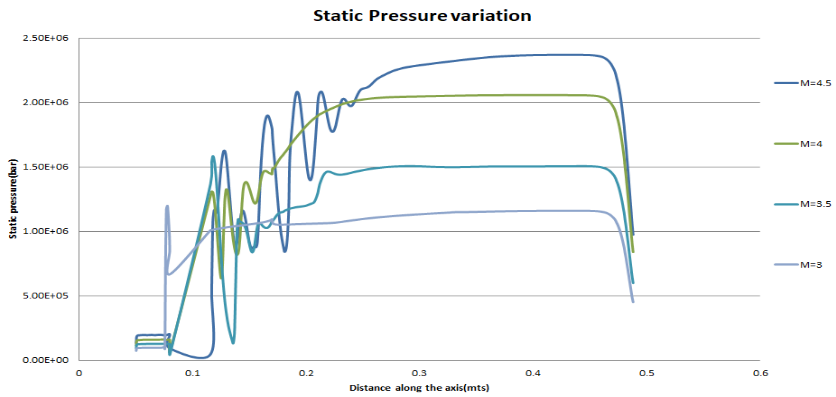

Figure 25: Pressure Variation Graph.

REFERENCES

1. *A. N, T. J. (1983). Exploding ramjet myths. National Defence, 18-23.*
2. *D. D, G. A. (2002). Aerodynamic optimization of air breathing propulsive system of ramjet powered missile. AIAA Paper no 2002–5546.*
3. *Moorthy, C. V., Srinivas, V., Prasad, V. V. S. H., & Vanaja, T. (2017). Computational analysis of a CD nozzle with 'SED'for a rocket air ejector in space applications. 7 (1). Pp 53, 60.*
4. *G. Raja singh Thandurai, B. S. Subhash Chandran, V. Babu, & T. Sundararajan. (May 2008), Numerical Analysis of Integrated Liquid Ramjet Engine. Defence science journal, vol. 58, No. 3, 327–337.*
5. *Hebrard. P, Laurent. G., & Torque. (1991), Experimental simulation and prediction codes for a Ramjet and ramrocket performances, ISOABE (pp. 1051-059.). U K: ISABE 91–7112.*
6. *Santhanam, G., Srinivas, C., Sree, C. K., & Prasad, S. S. Cfd Analysis of the Effect of Mach Number on Scramjet Combustion.*
7. *Laurent, j. M, C. (1996). Liquid fuell ramjet engine of tactical missile, 170, 423–46.*

AUTHORS PROFILE

Mr. M. Sadhiq has completed B.Tech in Aeronautical Engineering and M. Tech Aerospace Engineering from MRCET/JNTUH. His areas of interest are Aerodynamics and Computational Fluid Dynamics.

Mr MAMIDI AJAY SAGAR has completed BTech in Aeronautical Engineering and MTech in Aerospace Engineering from MRCET/JNTUH, and currently working as Assistant professor in School of Aeronautics, Neemrana, Rajasthan. His area of interest is High Speed and Experimental Aerodynamics. He had worked in DRDL as a Contract Engineer for one year.

Mr Rajashekar Rayudu has completed B.Tech Aeronautical Engineering and presently persuing M. Tech Aerospace Engineering at Malla Reddy college of engineering and technology, Hyderabad.

Ms D. Smitha has completed her B.Tech and M.Tech from JNTUH in Aeronautical Engineering. She has 15 years of experience in teaching. Presently she is persuing PhD in Mechanical Engineering from GITAM University Vizag. She has published and presented 5 papers in International Journals, International and National Conferences. Her areas of interest are Flight Mechanics and Composite materials.